Bellcomm

955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

date: August 24, 1971

to: Distribution

B71 08031

from: B. H. Crane

subject: Evaluation of Flight Planning with the Automated Task Scheduler (ATS) - Case 610

ABSTRACT

The first version of the Automated Task Scheduler (ATS) was tested on a representative flight-planning problem for Skylab missions. Limitations of this program make it advantageous for the flight planner to work out an overall plan for the timeline in advance of writing input data for the computer. A method was worked out in this study whereby the ATS can be used to do detailed scheduling of this overall plan on a day-by-day basis in a relatively convenient manner. Meanwhile, the program author, A. B. Baker, has modified the ATS to be compatible with an Interactive Schedule Generator (ISG), which gives the user much more freedom in constructing and modifying the output timeline.

(NASA-CR-121542) EVALUATION OF FLIGHT PLANNING WITH THE AUTOMATED TASK SCHEDULER /ATS/, CASE 610 (Bellcomm, Inc.) 20 p

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MEMORANDUM FOR FILE

1. Introduction

The Automated Task Scheduler (ATS) is a computer program that has been developed to explore the potential of a simplified scheduling algorithm for flight-planning applications. The first version of this program schedules tasks automatically in a batch mode. Subsequent modifications to the program have made it compatible with an Interactive Schedule Generator (ISG), which permits the flight planner to schedule or erase tasks individually on an interactive basis. Batch scheduling of other tasks can be done by the modified ATS on the same timeline.*

This memorandum reports a demonstration of the first version of the ATS on a representative scheduling problem. Objectives of the demonstration task were to schedule at least a portion of every experiment assigned to the SL-2 mission within a man-month of flight-planning time. Following is a brief description of the resulting timeline and the manner in which the ATS was used in developing it.

2. SL-2 Timeline

A number of previous studies were available upon which to base scheduling of high-priority medical, ATM, and EREP experiments for SL-2.** These studies assume an SL-1 launch at 9:30 a.m., November 9, 1972. Although the current launch date for SL-1 is April 30, 1973, the earlier launch date is still broadly representative of the types of scheduling problems encountered on any Skylab mission.

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*These two versions of the ATS have been documented by the program author, A. B. Baker, in References 1 and 2.

** ATM - Apollo Telescope Mount.
EREP - Earth Resources Experiment Package.

One of these studies, Reference 3, recommends that the beginning of sleep occur at 8:00 p.m. EST during SL-2 in order to have all potential EREP opportunities occur during the "afternoon" portion of the crew day. This plan permits a sequential trial of M092, M093, and M171 (or M092, M093 only) to be scheduled in the late "morning" of the crew day without interfering with EREP.* Reference 4 notes that a maximum number of ATM opportunities can be obtained that each permit a full fifty minutes of solar ATM observations if sleep can be scheduled up to plus or minus thirty-one minutes away from the nominal time on some days. Other ground rules and assumptions used in this study may be found in Table I.

Corollary experiments were scheduled within the general framework established for medical, ATM, and EREP experiments. Major requirements affecting the scheduling of corollary experiments were obtained from the October 1970 Baseline Reference Flight Plan (Reference 6) and current versions of Experiment Requirements Documents (ERD's). Time was not available to make a detailed check of all requirements, but an attempt was made to consider as many requirements as possible that were known to have a significant effect on scheduling.

The month allotted for scheduling tasks was spent almost entirely on the mechanics of preparing and processing ATS runs. Due to the pressure of time, a few experiments were not explicitly scheduled in the final timeline, although opportunities had been provided for them in planning the schedule. Table II lists all experiments that were explicitly scheduled, and Table III shows mission days on which these experiments are scheduled in the timeline. Table III also lists other in-flight experiments that were assigned to the Skylab program when this study was performed. Experiments in this list that were not explicitly scheduled have a comment indicating whether opportunities were available.

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*At the time this study was performed, M092 and M093 required trials every third day for each crewman, and M171 was to be performed five times during the mission for each crewman. These requirements can be met by scheduling one trial of M092/M093 every day with a rotation of crewmen serving as subject. M171 is performed after M093 on five of these trials per subject during the mission. The new requirement is that M171 simply replace M093 whenever it is performed. The data obtained from M171 is now deemed to fulfill the M093 requirements on those days.

TABLE I

GROUNDRULES AND ASSUMPTIONS

LAUNCH TIMES:	• SL-1: 9:30 AM EST, NOVEMBER 9, 1972 • SL-2: ~9:00 AM EST, NOVEMBER 10, 1972
MISSION DURATION:	• UP TO 28 DAYS FROM SL-2 LIFTOFF
MISSION DAYS:	• DAY 1 BEGINS AFTER THE FIRST SLEEP PERIOD • DAYS 0 – 1 ARE RESERVED FOR SL-2 LAUNCH, RENDEZVOUS WITH THE WORKSHOP, AND WORKSHOP ACTIVATION • DAYS 26 – 28 ARE RESERVED FOR ATM FILM RETRIEVAL, WORKSHOP DEACTIVATION, AND CREW RETURN TO EARTH IN THE CM • ONLY DAYS 2 – 25 ARE EXPLICITLY SCHEDULED
SLEEP TIMES:	• AN EIGHT-HOUR SLEEP PERIOD FOR ALL THREE CREWMEN IS NORMALLY SCHEDULED BETWEEN 8:00 PM EST AND 4:00 AM EST • SCHEDULING OF THE EIGHT-HOUR SLEEP PERIOD CAN VARY BY AS MUCH AS ± 31 MINUTES ON SOME DAYS TO MAXIMIZE THE NUMBER OF ATM/EREP OPPORTUNITIES THAT FALL ENTIRELY WITHIN WORKING HOURS
CREW WORKING HOURS:	• CREW WORKING HOURS BEGIN TWO HOURS AFTER THE CREW AWAKENS AND END AT THE START OF DINNER, FOUR HOURS BEFORE THE BEGINNING OF THE NEXT SLEEP PERIOD • A LUNCH PERIOD (ONE HOUR) AND M071 (.5 HOUR) IS SCHEDULED AT FOUR HOURS ± ONE HOUR AFTER THE WORKING DAY BEGINS • 4.5 MAN-HOURS ARE RESERVED FOR SYSTEMS HOUSEKEEPING AND 1.5 MAN HOURS ARE RESERVED FOR CREW PERSONAL HYGIENE DURING WORKING HOURS
M092, M093, M171:	• ONE SEQUENCE OF EXPERIMENTS M092, M093, M171 (OR M092, M093) IS SCHEDULED EACH DAY (DAYS 2 – 25), ROTATING SUBJECTS ON DIFFERENT DAYS
DAYS OFF	• DAYS 8, 15, AND 22 ARE DAYS OFF FROM SCHEDULED EXPERIMENTS EXCEPT FOR M071, M092, M093, AND M171
EREP EXPERIMENTS	• TIME IS RESERVED FOR NINE EREP PASSES
ATM EXPERIMENTS	• ONE-MAN TIME IS RESERVED FOR ATM EXPERIMENTS DURING EACH OPPORTUNITY OCCURING WITHIN WORKING HOURS OR WITHIN A TWO-HOUR PERIOD IN THE "EVENING" PORTION OF THE CREW DAY, EXCEPT DURING DAYS OFF OR DURING A PASS RESERVED FOR EREP • LUNCH IS NOT EXPLICITLY SCHEDULED FOR THE CREWMAN ASSIGNED TO ATM • ATM EXPERIMENTS MAY BE PERFORMED ON DAYS OFF IF THERE IS A SOLAR FLARE OR OTHER UNUSUAL EVENT

TABLE II. SCHEDULED EXPERIMENTS

A. EXPERIMENTS THAT ARE FULLY SCHEDULED

- ATM - Apollo Telescope Mount (time reserved)
- EREP - Earth Resources Experiment Package (time reserved)
- M071* - Mineral Balance
- M092 - In-Flight LBNP
- M093 - Vectorcardiogram
- M131 - Human Vestibular Function
- M171 - Metabolic Activity
- M509 - Astronaut Maneuvering Equipment
- M512 - Materials Processing in Space
- S009 - Nuclear Emulsion
- S015 - Zero-G Single Human Cells
- S149 - Particle Collection
- T003 - In-Flight Aerosol Analysis
- T025 - Coronagraph Contamination Measurement
- T027 - ATM Contamination Measurement

B. EXPERIMENTS THAT ARE ONLY PARTIALLY SCHEDULED

- S019 - UV Stellar Astronomy
- S020 - UV/X-Ray Solar Photography
- S063 - UV Airglow Horizon Photography

*M071 includes daily activities of M073, M074, and M172.

TABLE III. TIMELINE SUMMARY

Expt.	CM	Mission Day[1] 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
M071[2]	All	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M074	Any	(Calibrations not scheduled -- opportunities available).																							
M172	Any	(Calibrations not scheduled -- opportunities available).																							
M092	1	X			*			X			*			X			*			X			X		
M093	2		X			*			X			*			X			*			X			X	
M171	3			X			*			X			*			X			*			X			X
ATM	Any	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M131	1				B									B									B		
	2			A		B	A				A			B		A				A			B	A	
	3			A		B	A				A			B		A				A			B	A	
EREP	All									X	X	X	X	X											
M151	Any	(Performed in conjunction with other experiments -- not scheduled).																							
T003	Any										X										X				
M512	Any	X	X	X		X			X	-	-	-	-	-	-	-	-	X							
T027	Any	X	X	X	X							X	-	-	-	-	X								
M509	1				X					X						X				X					
D021/24	Any	(Samples retrieved in EVA on Day 26).																							
S073	Any	(Some opportunities made available for each of seven required sequences).																							
S149	Any																X	-	-	X					X
M479	Any	(Some opportunities available after completion of M512 on Day 18).																							
T013	All						X																		
T025	Any	X	X	X	X																				
S019	Any																				X		X		X
D008	Any	(Not scheduled -- opportunities available).																							
S009	Any				X																				X
S020	Any					X																			
S063	Any									σ	σ	σ	σ	σ			X	X	X						
T020	All	(No opportunities available if S073 spans Day 24).																							
M415	N/A	(No crew interface).																							
S015	Any			X						X															
T018	N/A	(No crew interface).																							
M487	All	(Scheduling requirements undefined).																							
M133	Any	(Measurements are made during sleep; no additional time is scheduled).																							

[1] Numbers denote full working days (e.g., day 2 occurs after the second sleep period).

[2] Daily activities associated with M071, M073, M074, and M172 are scheduled as M071.

* M092/M093 only

A,B Modes of M131

σ Ozone photography of S063 scheduled as a part of EREP.

Man-hours of both scheduled and unscheduled time are shown in Table IV for various categories of activity. One hundred fifteen man-hours of crew time are potentially available for scheduling additional experiments based on the ground rules adopted in this study. Figure 1 shows distributions of this time over the mission for each crewman separately and for all crewmen combined.

The uneven distribution of time in Figure 1 is largely due to the fact that all experiments were not scheduled. The method of scheduling also contributed to an especially heavy concentration of activity on some days, however. Days on which many experiments were competing for time were generally scheduled first. Days 14 and 16, for example, are heavily scheduled because of frequency requirements associated with experiment M131 in addition to other medicals, ATM experiments and scientific-airlock experiments that use time on these days. Otherwise experiments were scheduled sequentially throughout the mission from beginning to end. Days early in the mission were scheduled rather fully with higher-priority experiments so as to schedule as many other objectives as possible in the remaining time. In a second draft of this flight plan it would be advantageous to re-distribute scheduled crew time as evenly as possible within working hours.

3. Discussion of the Automated Task Scheduler

The ATS is based upon the assumption that a set of in-flight tasks for a space mission can be scheduled one-at-a-time in a pre-determined order of priority. Each task is defined by a set of task-description statements that represent major scheduling requirements in standard formats. When a task is scheduled, the program arbitrarily selects the earliest time that meets all requirements stated in the task description, taking into account the resources already committed to previously scheduled tasks. If several repetitions of a task are being scheduled as a single objective, the first performance is scheduled at the earliest time that permits a maximum number of repetitions up to the desired number.

Restrictions on scheduling a task may be imposed by actual requirements of system design and crew procedures, or they may be imposed arbitrarily by the flight planner as a part of his particular approach to scheduling. Either type of restriction is specified to the ATS as a task

TABLE IV. CREW TIME SUMMARY

			Man-Hours*
A. SCHEDULED TIME			
1. Daily Non-Experimental Activities			959
2. Medical Experiments			223
3. ATM Experiments			150
4. EREP Experiments			17
5. Corollary Experiments			71
		Total Scheduled Time:	1420
B. UNSCHEDULED TIME			
1. Systems Housekeeping and Personal Hygiene			126
2. Free Time Not Available for Experiments			67
3. Time Remaining For Scheduling Experiments**			
a. Segments $\geqslant$ 30 minutes	(86)		
b. Segments < 30 minutes	(29)		115
4		Total Unscheduled Time:	308
		TOTAL CREW TIME IN 24 DAYS	1728

*All times rounded off to the nearest whole man-hour.

**If some segments less than thirty minutes are used for systems housekeeping, more than 86 man-hours will be available in segments of at least thirty minutes for scheduling experiments.

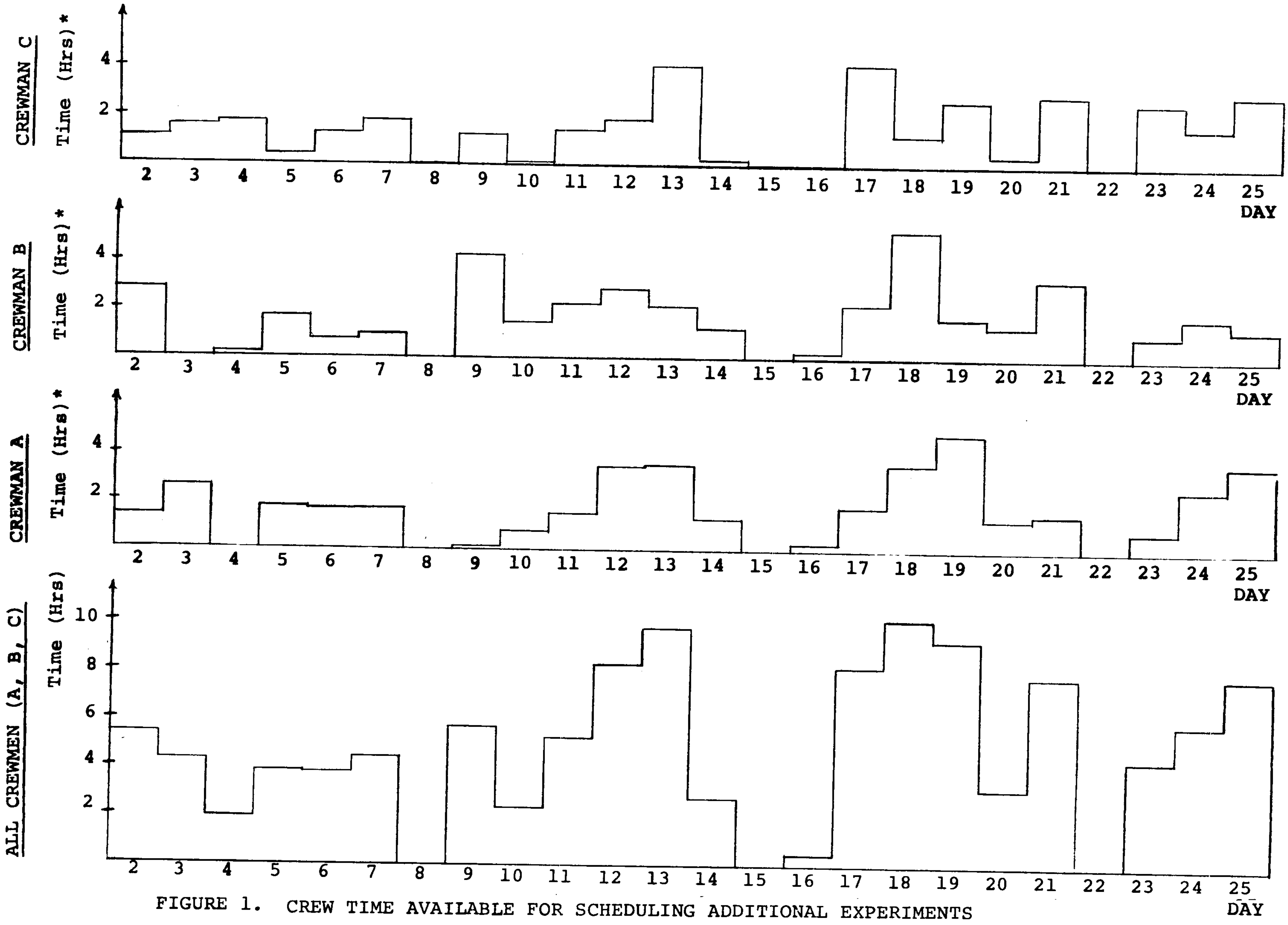

FIGURE 1. CREW TIME AVAILABLE FOR SCHEDULING ADDITIONAL EXPERIMENTS

*Assumes that systems housekeeping tasks are distributed as evenly as possible among the three crewmen.

requirement. Statements in a task description that arbitrarily restrict the flexibility inherently available for scheduling a task will be referred to as scheduling instructions in this memorandum to distinguish them from actual task requirements. A scheduling instruction can implicitly fulfill one or more requirements that are not inherently as restrictive as the statements used in a task description.

Formats available for task description in the ATS permit specification of scheduling constraints directly in terms of mission time or in terms of time relative to some event. Using the fact that tasks are to be scheduled in a definite order, a given task can be either enabled or inhibited relative to another task that precedes it in the scheduling order.

Times at which a task can be scheduled can also be constrained indirectly by resource requirements. A task that fully occupies a specific crewman or piece of equipment, for example, can be scheduled only where this resource is available over the required interval of time. Resources used at specified rates are subject to the limitation that requirements from all previously scheduled tasks plus a new task do not exceed a specified maximum limit at any mission time. Tasks that use a given amount of a resource can be scheduled only if the sum of this requirement with those of all previously scheduled tasks does not exceed the total quantity of this consumable for use on this mission.

In short, any schedule produced by the ATS is a straight-forward consequence of five types of input data:

1. The tasks included in the run,

2. The order in which these tasks are to be considered for scheduling,

3. The number of repetitions specified for each task,

4. Scheduling restrictions included in each task description, and

5. Overall limits on the rates at which resources can be used (e.g. electrical power) or the total amount of a

resource available (e.g. oxygen allocated for experiments).

3.1 Efficient Task Scheduling

The ATS was designed with the idea that the primary means of controlling the output would be the order in which tasks were considered for scheduling. Ideally, only actual task requirements would be included in the task descriptions. Tasks with highly restrictive requirements would be considered first while there was still plenty of room in the timeline. Other tasks with less restrictive requirements would then be scheduled in the remaining opportunities.

In practice, this strategy is not adequate for doing Skylab flight planning with the ATS. One aspect of this problem is that Skylab flight planning is sufficiently complex that tasks can not be scheduled efficiently by merely finding a particular order in which to consider them. It is necessary to incorporate a large number of scheduling instructions into the ATS task descriptions in addition to requirements in order to force tasks to schedule in an acceptable manner. The following example from SL-2 gives a simplified illustration.

Lack of availability of a scientific airlock is one of the primary factors that limits the successful completion of all experiment objectives assigned to the SL-2 mission. It is desirable to operate each scientific-airlock experiment as often as possible on any given day while it is mounted. For an experiment that must be operated only on non-consecutive orbits, three trials are the most that can be scheduled in any one day.

Every day on which a scientific-airlock experiment is scheduled will also include a sequential medical trial just prior to lunch. The medical trial, lunch, and time allotted to M071 occupy two crewmen. The third crewman is covering the ATM console during this time. In most cases it is possible by judicious scheduling of the medical sequence to get in one trial of the scientific-airlock experiment immediately before the sequential medical trial, one just after lunch, and a third before the end of the working day. Neither experiment can be scheduled without anticipating the scheduling requirements of the other if both are to be scheduled.

Many such interactions occur in the scheduling of Skylab experiments. These interactions must be considered as a group in solving the overall problem. When the requirements of more than one scientific-airlock experiment are considered, for example, competition develops for crew time on certain days of the mission as well as for total time in a given scientific airlock. Some of these experiments must be done early in the mission, mid-mission, and late in the mission; some must be done only during intervals of the mission that have a particular phase of the moon or a beta-angle that falls within given limits.*

A related constraint is that non-scientific airlock experiments M509, T020, and T013 can only be performed when certain scientific-airlock experiments are not mounted. In addition, trials of M509 or T020 must be separated by enough time to avoid creating an unacceptable nitrogen overpressure in the cabin atmosphere. Since both experiments can not be completed on SL-2, due to this constraint, trials must be scheduled as close together as possible to maximize the return from these experiments.

Still another factor to be considered is that no crewmen are available to perform scientific-airlock experiments when trials of M131 are being performed. These trials require up to 4.5 man-hours on several mission days, which must occur at acceptable frequencies.

To schedule all of these interacting experiments efficiently, a coordinated sequence must be worked out that takes into account both the opportunities for detailed scheduling of each experiment and requirements that create competition for time on certain mission days. Scheduling of any one experiment must anticipate the requirements of many other experiments in order to successfully complete a reasonable number of objectives.

3.2 Task Requirements

In addition to the problem of scheduling tasks efficiently, some types of requirements cannot be stated directly on a task-by-task basis in available ATS formats. As one example from the previous illustration, there is no

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*Beta is the angle between the spacecraft orbital plane and the line between the center of the earth and the center of the sun.

way to specify that an experiment occupies the scientific airlock from the time it is mounted to the time it is stowed again, whether or not a specific task using this equipment is underway. One solution to this problem is to include artificial requirements in the task descriptions that insure a particular sequence of all tasks that use a given scientific airlock. The same device also covers other requirements mentioned in the previous illustration that cannot be stated directly, such as a requirement that certain experiments not be mounted in the scientific airlock during M509, T013 and T020, or limitations on both the partial pressure of nitrogen in the cabin and total pressure of the cabin atmosphere.

Scheduling instructions may also be needed to account for other types of Skylab experiment requirements. In some cases, for example, a requirement states that the same crewman should perform two trials of an experiment that are scheduled separately, but it does not matter which crewman is selected. The only way to assure that such a requirement is met in the ATS is to assign a specific crewman to both tasks, even though one may not know which one is the best choice. These and other examples of scheduling instructions needed to account for various types of Skylab experiment requirements are discussed in Reference 5.

Any computer format will force some decisions to be made in advance of scheduling that may arbitrarily limit scheduling flexibility. If a task is to be scheduled early in the mission, for example, the computer requires a quantitative definition of early. There is sometimes considerable uncertainty in exactly how long a task will take or how much time is actually required between two tasks that must be separated. These examples, however, illustrate relatively minor, arbitrary decisions that are built into a precise description of task requirements. In contrast, the kinds of scheduling decisions in the previous examples involve considerable foresight into the overall solution of the scheduling problem.

4. Scheduling Approach

An attempt was made in this study to approach scheduling in a manner that would minimize both the amount and complexity of ATS input data required to produce an acceptable timeline. Before making any ATS runs, an overall plan of the mission was prepared in which experiment tasks were tentatively assigned to specific mission days. Implicit in such a plan are major frequencies of task repetitions on different mission days and major sequences of other tasks over the mission. Preparation of the overall plan also required preliminary decisions as to which experiment objectives could be fully scheduled on this mission and which should be curtailed in the interest of scheduling at least a portion of every experiment. The overall plan was updated whenever detailed scheduling of each day indicated a need for reassigning some tasks to different mission days.

Detailed scheduling of each mission day was done using the ATS. Task descriptions used for this scheduling generally included statements of task priority, objective, crew requirements, and in some cases a specific relationship to events such as orbital noon. Other statements in the task descriptions structured relationships among tasks to be scheduled on each day in a manner that satisfied their requirements and appeared promising for scheduling. The ATS determined the feasibility of scheduling the tasks in this manner by calculating exact start-times relative to events, specific crew commitments, and other imposed constraints.

This approach to scheduling makes the flight planner responsible for keeping track of most task requirements on his own. In constructing the overall plan he must take into account any factors that limit mission days on which some tasks can be scheduled, such as beta-angle or phase of the moon. Such parameters were entered on the overall plan to facilitate reassignment of tasks to different mission days, if necessary. Construction of the overall plan also eliminates some potential conflicts among tasks because they are not being scheduled on the same day. The remaining conflicts that can occur among tasks assigned to the same day were often resolved by the flight planner by use of scheduling instructions in the task descriptions.

5. Two Methods of Implementing this Approach

One method of doing detailed scheduling on a day-by-day basis with the ATS is to use time cards to force each task to schedule on the day to which it is assigned in the overall plan. At any point in the scheduling process, all tasks to be scheduled throughout the mission appear at the input to each run. The output of each run shows all tasks that have been scheduled and the status of any tasks that were considered but not scheduled.

A second method of scheduling tasks on pre-assigned days with the ATS is to make each mission day a completely independent run. The run for any given day would be repeated only when the schedule for that day is to be changed. Otherwise, the mission is built up as a series of successive runs for different mission days. Following is a comparison of some of the most salient differences between these two methods of implementing the same overall approach to scheduling.

5.1 Runs and Charge Units

Using the first method, all mission tasks need not be considered for scheduling in a single run. Instead, a history tape can be made each time a run schedules tasks onto the mission timeline. Subsequent runs can then initialize from any point in this scheduling process that is contained on an available history tape. Each run, for example, might add one mission day to the overall schedule. In this case each run would have a relatively short running time. As the schedule developed, however, longer running times would be required to change any portion of the schedule that had been put on the history tape early in this process, because all subsequnt scheduling would have to be repeated.

The second method schedules only one mission day per run by definition. Each of these runs would have the minimum running time obtainable with the ATS for scheduling one mission day. After the scheduling process has been completed, however, it would take longer to reproduce a mission by twenty-four separate runs than by one run that scheduled all twenty-four days that were scheduled in this study.

A similar observation can be made for any modification of the overall schedule that affects more than one mission day. If all tasks have been scheduled on a single record by the first method, a change at a given point in the original scheduling process causes all subsequent scheduling to be repeated. A large penalty may be incurred if a task is changed that was originally scheduled early. For a prolonged scheduling process in which there are many small changes, independent runs would probably be advantageous in terms of overall charge.

5.2 Task-Description Data

Scheduling all tasks onto a single record by the first method complicates the problem of task descriptions in a number of ways. One is that a single, uniform system of priorities must be devised that gives the order in which tasks are to be considered for scheduling. Small changes such as a reversal in the order of scheduling two tasks could be accomplished very conveniently by this system. Substantial changes in the order of scheduling tasks may require extensive re-numbering, however. It is inefficient to leave space in the numbering system to absorb changes because many program functions, including the history tape, are controlled by priority numbers.

A second complication that occurs if all tasks are scheduled onto a single record stems from the rule that all task repetitions must have different task names unless they are scheduled in one transaction as a single objective. Daily tasks, for example, can be scheduled in advance as a multiple objective only if no flexibility is to be permitted to accommodate scheduling of other tasks. Some daily tasks such as medical experiments, ATM experiments, and lunch, however, depend upon how other experiment tasks are to be scheduled on the same day. It is necessary to schedule these tasks independently, unless the entire mission is worked out at once and there is some way to coordinate the action of the objective card with the scheduling of other tasks. Since the flight planner does not know at the outset how much flexibility will be needed, it would be safest to schedule all daily tasks independently.

A consequence of this multiplicity of names for one task is that all enable and inhibit statements of other tasks must supply the correct name for each repetition of the task to which the statement applies. This rule is only a small inconvenience when one of these statements is being used exclusively as a scheduling instruction relating two tasks on a given day. To express a task requirement, on the other hand, one must have a duplicate enable or inhibit statement for every repetition of the second task that is scheduled independently at a higher priority. These statements cannot be included for repetitions of the second task that have not yet been considered for scheduling. This kind of data manipulation requires considerable bookkeeping for the flight planner that has little to do with solving the scheduling problem.

The rules for priorities and task names are the same if each day is scheduled as an independent run, but in each case they apply only to the scheduling for one day. All daily tasks can now be scheduled with the same names and usually the same priorities on different days. Thus a single task description can be listed on a data bank for each of these tasks and used as a basis for scheduling that task in all runs. In addition, only task repetitions that are scheduled separately on the same day require different task names, such as a succession of observation tasks for a scientific-airlock experiment. Thus independent runs for each day greatly simplify the preparation of input data for each run and any manipulation of this data required to change the schedule.

5.3 Consumable Analysis

Scheduling all tasks onto a single record has the advantage that total quantities can be calculated for consumables used during the mission. The capability to compute sub-totals over a given day is not provided, however, unless a different resource name is used for the quantities to be totaled on each day. One example of this kind of sub-total would be reserving time for systems housekeeping on each day without actually scheduling the tasks, as was done in this study. If a different resource name had to be used on each day, the appropriate resource statement could be put in a task description only after the task had been tentatively assigned to a given day. The statement would have to be changed to schedule the task on another day.

Independent runs for each day provide the simplest means of constraining sub-totals of a consumable over each day. Obviously the disadvantage is that the computer does not supply total quantities of consumables used over the mission. This data must be obtained in a separate step by adding up the sub-totals from each run covering one day.

5.4 Automated Scheduling

Structuring the overall schedule by tentatively assigning each task to a specific mission day is a natural way to schedule most experiments. There are a few experiments, however, that can be scheduled almost anywhere in the mission that a crewman is available and other basic requirements are met. One example from Skylab is D008, which requires one crewman for fifteen minutes for trials within the South Atlantic Anomaly and one crewman for thirty minutes for trials at the northernmost latitudes of the spacecraft orbit.

If all tasks are scheduled on a single record, it is possible to search the full mission timeline for opportunities to schedule experiments such as D008 by simply omitting a time card in the task description. Since many opportunities exist, there is a good chance that D008 could be scheduled successfully after most other tasks had been scheduled, without anticipating its requirements in scheduling the other experiments.

The idea of searching the full mission timeline for opportunities is not compatible, however, with using different resource names to obtain sub-totals for man-hours (or other resources) on different mission days. To schedule an experiment by a full-mission scan and still obtain the man-hours sub-total, the flight planner would have to check for availability of crew time on various days, either before making the scan, or in retrospect after the task has been scheduled. In either case the task should be rescheduled on the same day in a second ATS run with the appropriate card added to the task description to update the resource named for man-hours on that day.

For the few experiments like D008, arbitrarily assigning these tasks to a specific mission day requires hand scheduling that might be done faster by computer. This limitation of making independent runs for each day covers a very minor aspect of the overall scheduling problem, however. Scheduling the vast majority of tasks efficiently requires the kind of coordination described previously for medical experiments, scientific-airlock experiments, and astronaut-maneuvering experiments on SL-2.

6. Method Used in This Study

The method of making independent runs for each mission day was selected for use in this study, even though a minimum of twenty-four separate runs were required to schedule days 2 - 25 of SL-2. It was felt that the time required to prepare all of these runs and to do post-scheduling analysis of mission totals was more than compensated by the relatively simple manner in which scheduling could be accomplished. Following is a brief description of the results of this decision.

6.1 Run Deck and Charge Units

The ATS does not presently have a direct capability for scheduling one day of the mission in a run. All ATS runs cover a ground-elapsed time (GET) from zero to a stated upper limit. This time scale must correspond to the time scale for events from the ephemeris tape. In this study it was most convenient to use dummy tasks to block out all crew time from zero to the beginning of the day to be scheduled and from the end of that day to the end of the mission. It was not convenient to use the mission duration to delimit the end of the day to be scheduled because this number is expressed in days and decimal fractions of days, GET. Crew working hours were keyed to sleep times expressed in days, hours, and minutes, GET.

A significant amount of time is required to set up independent runs. Although many control and data cards were the same in all run decks, many others varied slightly from day to day. Some examples are run titles, task descriptions for dummy tasks delimiting the beginning and end of each day, sleep times, crew assignments that rotate from day to day, corollary-experiment tasks included in the run, and resource limits for each day. Task-description cards that were identical for all decks were read in from a common data bank.

Twenty-four separate run decks were a distinct advantage once their initial preparation had been completed, however. Several days could be worked on in parallel, for example, running one while making edits to another. As the schedule for each day developed, modifications to the task description on the data bank were built up in each deck that produced an acceptable schedule. Since the data bank was not changed during the scheduling phase of the study, each deck contained a complete set of scheduling instructions for one day at any point in its development.

History tapes were not made with each run during the scheduling phase of this study. Although a history tape would have permitted making computer-generated plots of each run, a turn-around time of one or two days would be required to obtain each computer plot. Instead, a quick plot of the results of each run was usually made by hand to aid in examining the output schedule, correcting any errors, and making revisions in the schedule. History tapes were run for each day after all schedules had been completed so as to make ATS-generated plots of the final results.

A run for one mission day without a history tape had a very short running time (usually five to six charge units). This fact permitted a relatively short turn-around time in the computer, since priority is given to runs with a low maximum charge. Table V shows the total number of charge units spent on various phases of the study. A comparison of the charge for the twenty-four final schedules without history tapes (133) with the charge for the same schedules with history tapes (202) shows a considerable increase. By re-running the final schedule with a history tape at the same time as the plotter run, it was not necessary to save the twenty-four history tape files for any significant length of time.

6.2 Data Bank

Independent runs for each day were also compatible with a very concise and readable format for a task data bank. All tasks with fundamentally distinct requirements were listed on a common data bank that was used for all runs. This basic task description was read in by each run that attempted to schedule some repetition of this task. Any additional information needed to complete the task description for that run and provide specific scheduling instructions was added in the input data for that run. An equivalent task with a different task name had to be defined only if a second repetition of the task were scheduled on the same day in a separate transaction.

As noted previously, one advantage of making independent runs for each day is that daily tasks can be scheduled by a single set of task descriptions in each run. These tasks were listed first on the data bank in the order in which they were to be scheduled. Their task descriptions included almost a complete set of scheduling instructions, since a standard pattern of daily tasks is indicated by the ground rules covered previously in Table I. Only minor variations were required in the input to any given run to set the timing of sleep on different days and to rotate crewmen on some tasks.

Experiments not repeated on a daily basis were also listed on the data bank in alphanumeric order of their task names for easy reference. These task descriptions included

TABLE V. SUMMARY OF RUNS AND CHARGE UNITS

	No. of Runs	Charge Units	
I. RUNS THAT WERE COMPLETED			
A. SET UP FOR SCHEDULING			
1. Data Bank	10	35	85
2. Test Schedules	11	50	
B. SCHEDULE DEVELOPMENT			
1. Problems, Errors, Scheduling Decisions	26	211	344
2. Final Schedules	24	133	
C. PLOTTING OF RESULTS			
1. Re-Runs for History Tapes	24	202	325
2. Plotter Runs	24	123	
	SUBTOTAL:		754
II. RUNS THAT WERE NOT COMPLETED	21		81
	TOTAL:		835

only statements that were expected to hold for every repetition of the task that is scheduled in any run. One example would be a requirement that an experiment always be scheduled in a fixed relationship to orbital noon.

All task descriptions in the data bank had to have a title, priority, and objective. Daily tasks were given a fixed order of priority in groups numbered from one to five. Priorities on the data bank were completely arbitrary for most other experiment tasks, since priority numbers are simply a means of changing the order in which tasks are considered for scheduling in a given run. Experiment tasks could be scheduled in between any of the five groupings of daily tasks in a given run by assigning the same number as the group to be scheduled just previously, or they could be scheduled at the end with a priority of six or higher. This scheme gave an extremely simple means of adjusting priorities in any one run as compared to the number of priority levels that would be needed in full-mission scheduling.

The objective appearing in each task description on the data bank indicated the number of repetitions to be performed on one day, not the total objective. In most cases it was possible to anticipate the number of repetitions of a task to include in the objective on the data bank. Otherwise a new objective card was put into the run deck for a day on which a different number of repetitions was desired.

Statements that enable or inhibit one task on another generally had to be supplied with a specific run, since these statements apply only if both tasks are to be scheduled in the same run. These statements were often used to control how tasks scheduled on a particular day, in which case they would not be supplied as a part of the basic task definition anyway. Other enable and inhibit statements were used to express requirements, however. Because task names were not changed for different days, many enable and inhibit requirements could be punched in advance and simply inserted into a specific run deck whenever both tasks named on the statement were to be scheduled in this run.

Crew requirements also had to be supplied with a specific run in many cases where the requirement could be met by any crewman. Although one can specify any crewman as a task requirement in the available ATS formats, the program may miss some available opportunities for scheduling the task with the present logic. In this study it was desirable to assign a specific crewman to most of these requirements as one means of structuring how the tasks would be scheduled on a given day.

Although specific crew assignments cannot be anticipated for many tasks while writing the data bank, it is very useful to have general crew requirements listed on the data bank for use in making scheduling decisions and identifying which crewmen should be assigned in a given run. A dummy resource name was used for this purpose, such as "SUBJ", "OBS," or "CM," for "subject," "observer," and "crewman," respectively. All dummy resources were used at a fictitious rate with effectively no limit on the total rate at which these resources could be used. Since these dummy resources had no effect on the scheduling of a task, they did not have to be deleted when a duplicate requirement naming a specific crewman was inserted in a run.

A useful capability derived from scheduling only one day at a time is that a limit was placed on the number of man-hours scheduled in each day. One use of this device was to reserve 4.5 man-hours per day for systems housekeeping tasks without having to schedule all of these tasks in detail. The total amount of crew time required for each experiment was included in its task description on the data bank. Each scheduling run had as one input an appropriate limit on the amount of crew time available for scheduling experiments.

7. Conclusion

Many potential advantages are available from using computers to aid in the scheduling of mission operations. During this study, printouts of the task data bank and mission events were found to be very useful for reference in making scheduling decisions. Timelines produced by the ATS are also much more complete and precise than would be possible by hand without a prodigious expenditure of time. In addition, once an acceptable schedule has been obtained, it would probably be much easier to make small refinements by ATS re-runs than it would to perform the same process by hand.

For the types of scheduling problems typically found on Skylab missions, a significant amount of interaction is needed between the flight planner and scheduling by the ATS. Flight planner inputs to the program during scheduling are primarily directed toward the following two goals:

(1) scheduling tasks in a reasonably efficient manner so as to complete as many mission objectives as possible, and (2) assuring that the schedule meets all requirements that are not accounted for directly in ATS input formats.

The required interaction between the flight planner and the first version of the ATS can best be provided by dividing up the scheduling process into small segments that run independently. Independent runs covering one mission day were chosen in this study because it seemed most natural to make a preliminary overall plan of the mission by tentatively assigning tasks to specific mission days. Independent runs for each day were also compatible with a very concise and readable format for a task data bank to be used in all runs.

Acceptable daily schedules can be produced by independent runs of the ATS from relatively simple inputs as compared to the input data that would be required to produce the same results in full-mission scheduling. Building up a full-mission timeline on a single record may require a complex structure of equivalent tasks, task priorities, consumables data, and a considerable number of scheduling instructions in the task descriptions. These complexities impede development and modification of the mission timeline. They also require that the flight planner have substantial knowledge of the desired schedule in order to account for all requirements and schedule a resonable number of mission objectives.

The simplicity of the task descriptions used in this study made the production of a demonstration timeline manageable within a limited period of time. This approach had the disadvantage that the flight planner had to keep track of most task requirements on his own. In addition, a significant amount of time was consumed in preparing separate run decks for each mission day. Despite the simplicity of the ATS data bank and scheduling approach used in this study, a similar timeline could probably have been produced by hand in less time than was required by computer.

The Interactive Schedule Generator (ISG) was constructed by A. B. Baker to provide a more direct interaction between the flight planner and an updated version of the ATS. This program has many advantages such as the capability for a flight planner to retrieve selected information from ATS data files on a remote terminal, schedule tasks himself, or erase a task from an existing timeline. Although some of the problems of data manipulation described above should still be improved, the ISG is a clear step in the right direction.

1025-BHC-li

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